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The production of custom variable neutral density filters using film and a computer controlled imaging device

Gregory A. Hermanson

THE PRODUCTION OF CUSTOM VARIABLE NEUTRAL DENSITY FILTERS USING FILM AND A COMPUTER CONTROLLED IMAGING DEVICE

by

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A thesis submitted in partial fullfillment of the requirements for the degree of Bachelor of Science in the College of Graphic Arts and Photography of the Rochester Institute of Technology.

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ABSTRACT

A system for generating custom variable neutral density filters has been built, characterized, and demonstrated. The desired densities for a neutral density filter are entered into the controlling computer as a function of distance. The program which generates the filter density profile is designed to vary the exposure time by controlling the velocity of the film as it moves under a slit aperture. A custom illumination system was designed and built to provide constant lamp output. The technique can provide the film with the exposure necessary to produce a given density profile.

ACKNOWLEDGEMENTS

The author wishes to sincerely thank Gary Dir who agreed to act as thesis advisor for this project and gave valuable support and encouragement throughout the study.

A special thanks goes to Al Fisher, Herman Hermanson, and Ed Urbanek of Xerox Corporation for their time and technical assistance in designing, constructing, and controlling the hardware assembled in this project.

The author would really like to thank Marcy Levin for her loving support and help throughout the year, but due to limited space, I won't.

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INTRODUCTION

A nonselective neutral density filter is a filter that is both visually neutral and has attenuation coefficients that are constant over the desired spectral range(1). These filters are commonly made from colloidal carbon (dispersed in gelatin), photographic silver, inconel, metallic films, and mechanical devices such as metal mesh screens, iris diaphragms, and rotating sector wheels(2). They are available from a number of manufactures(3). The inverse square law can also be used as a non-selective homogeneous light reduction tool. However, space constraints often make it impossible to use this property.

The filters that are commercially available are either of a uniform, circularly or linearly varying, or stepped density(4). While these filters come in standardized density gradients, the requirements for a specific application of a neutral density filter may dictate the use of a filter with density characteristics other than the standards available. In order to adopt the available filters to the specific uses, creative photographic skills are needed. Consequently, it would be advantageous to develop a device and a procedure which can be used to make neutral density filters according to the specific application requirements.

Most Kodak filters are made by dissolving suitable organic dyes in liquid gelatin and coating the proper amount of the solution onto prepared glass. After the coating is dry, the gelatin film is stripped from the support material and coated with lacquer(4). Kodak Wratten No. 96 neutral density filters are made by dispersing colloidal carbon in a gelatin and adding dyes to produce a selective neutral density(5). While these processes produce good nonselective neutral density filters, they would be expensive and unwieldly to implement for the production of a limited quantity of custom designed filters.

Thin evaporated layers of inconel on glass yields an excellent nonselective homogeneous neutral density filter with very little scattering(6). Again, however, the manufacturing of a single custom designed filter might be cost prohibitve.

Photographic silver can be used to produce a relatively good nonselective neutral density filter for visible and infrared use. The neutrality is good in the visible spectral region, although a transmittance window occurs at about 318 nm(7). A filter made from photographic silver will have a high Callier Q factor(8), and therefore should not be used in a beam forming a high quality image(9). This type of filter could be used in numerous situations where the scattering properties would not adversely affect the optical system. Accordingly, if the filter must be used in the imaging beam, a dye coupling process can be used and the silver can be bleached out. Photographic silver's affordability and ease of generation make it desirable for making custom filters.

In the design of a process for making variable density filters to specification, one must first consider the design of the exposure modulation device. While this device could be designed in many different ways to produce the desired results, the basis for all these designs is the same. The exposure modulator must be able to vary the exposure of the film, thereby acheiving the proper densities to meet the demands of the specific application.

Exposure H, is formally defined in sensitometry as the product of illuminance E (lux) on the film and the time T (seconds) for which the film is exposed, or $H = E \times T$ (10). The illuminance can be modulated by using different apertures, varying the distance from the light source to the exposure plane, or by changing the intensity of the light source itself.

The exposure can also be controlled by varying the amount of time that any given section of the exposure plane is illuminated. This is done by moving the exposure plane past a stationary aperture or by moving the aperture over a stationary exposure plane. Before a method is chosen, the main elements of the exposure modulator should be examined.

The SPSE Handbook(11) lists the important elements of a sensitometer. The proposed exposure device will use these same basic elements listed below:

LIGHT SOURCE: Provides a known luminous intensity and spectral composition.

PHOTOGRAPHIC MATERIAL: Its surface is referred to as the exposure plane and would be exposed uniformely in the absence of the modulator.
EXPOSURE MODULATOR: Alters the exposure so that various areas of the exposure plane receive a range of precisely determined different exposures.
SHUTTER: Determines the exposure time. Sometimes the light source or the exposure modulator functions also as a shutter, but most often the shutter is a separate device(12).

A conceptual diagram of the exposure device which incorporates these ideas is shown in Figure 1.

The most important characteristics of the light source are its reproducibility and its ability to provide a uniform illumination across the exposing aperture. These qualities can be easily implimented by mounting an incandescent bulb with a monoplane filament at a distance sufficiently far from the exposure slit so that the falloff in illuminance(13) is negligible. This bulb should be mounted directly over the center of the slit aperture in order to obtain the most consistent illumination of the aperture. A current regulator will be used to ensure a relatively constant lamp output.

The easiest variable to hold constant in the exposure device is the illumination of the exposure plane. This is done by using the previously mentioned light source to illuminate an aperture of constant width. The width of the aperture can be changed allowing greater flexibility in the fabrication of the filters.

Assuming that the illuminance is held constant, the exposure must be modulated by varying the amount of time any one section of the exposure plane is illuminated. This will

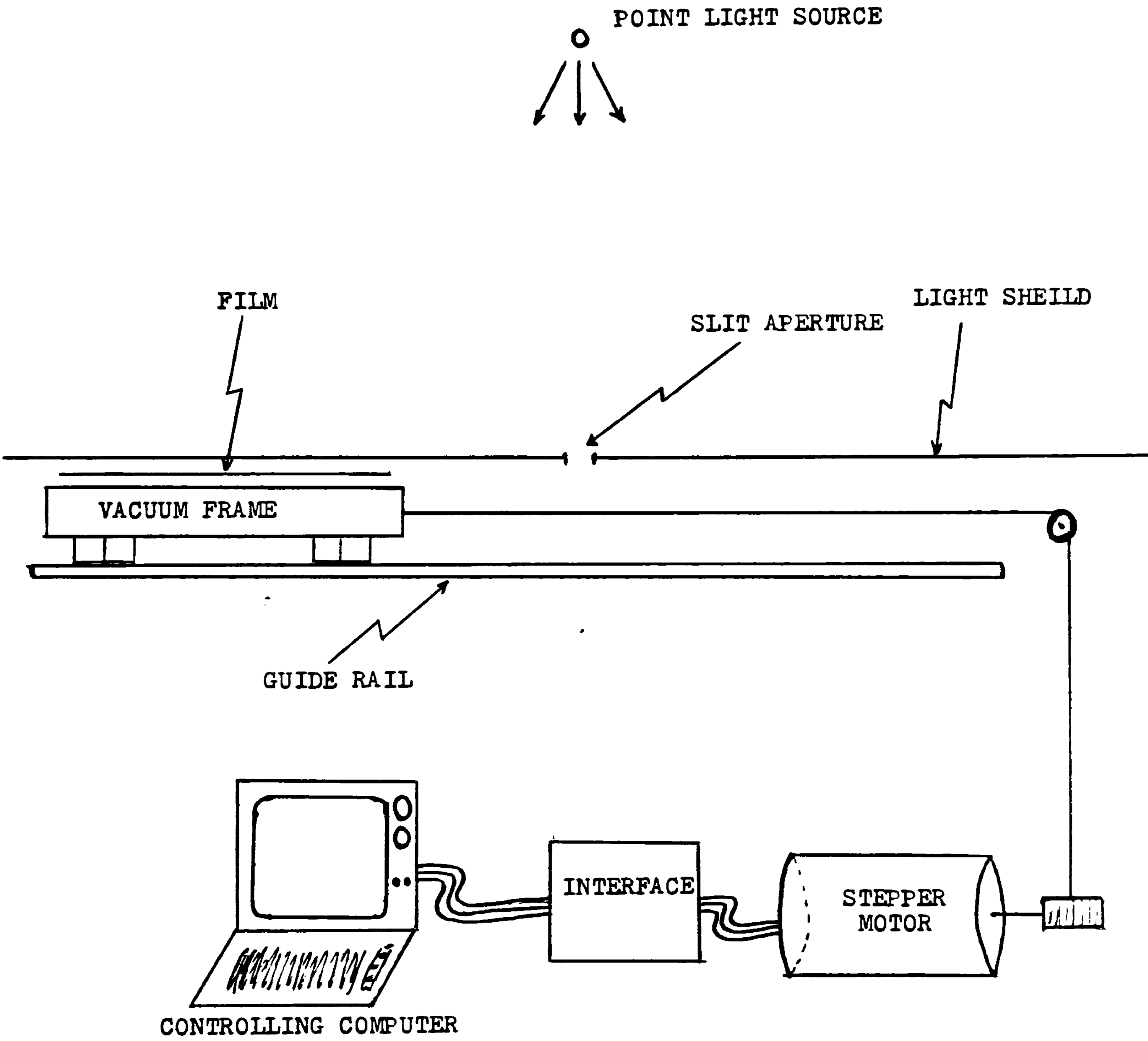

Figure 1: Conceptual diagram of device

be done by moving the exposure plane past the aperture in a controlled fashion to generate the desired densities. The movement within the exposure plane will be accomplished by a stepper motor controlled by a computer program.

In order to produce a filter with uniform density in any one section, it is necessary to give this section a uniform exposure. This means that all parts of the film in this section must be exposed to the same level of illumination for an equal amount of time.

As the film travels behind the illuminated slit, there are three areas where exposure could be taking place,(Figure 2). In the center section, the film is exposed with light directly from the bulb. In the areas on either side of this direct exposure area, the film could be exposed by light which was reflected or diffracted around the edge of the aperture.

In practice, almost all the indirect light can be blocked out. If a slow speed film is used and a large aperture width (relative to the step size) is chosen, the amount of exposure actually occurring in the areas not directly illuminated will be insignificant compared to the exposure from the direct illumination. This implies that the easiest way to achieve uniform exposure is to choose a large aperture size.

Conversely, if a large change in density over a short distance is required, the exposure must be able to be varied rapidly. To do this, a small aperture width (relative to the

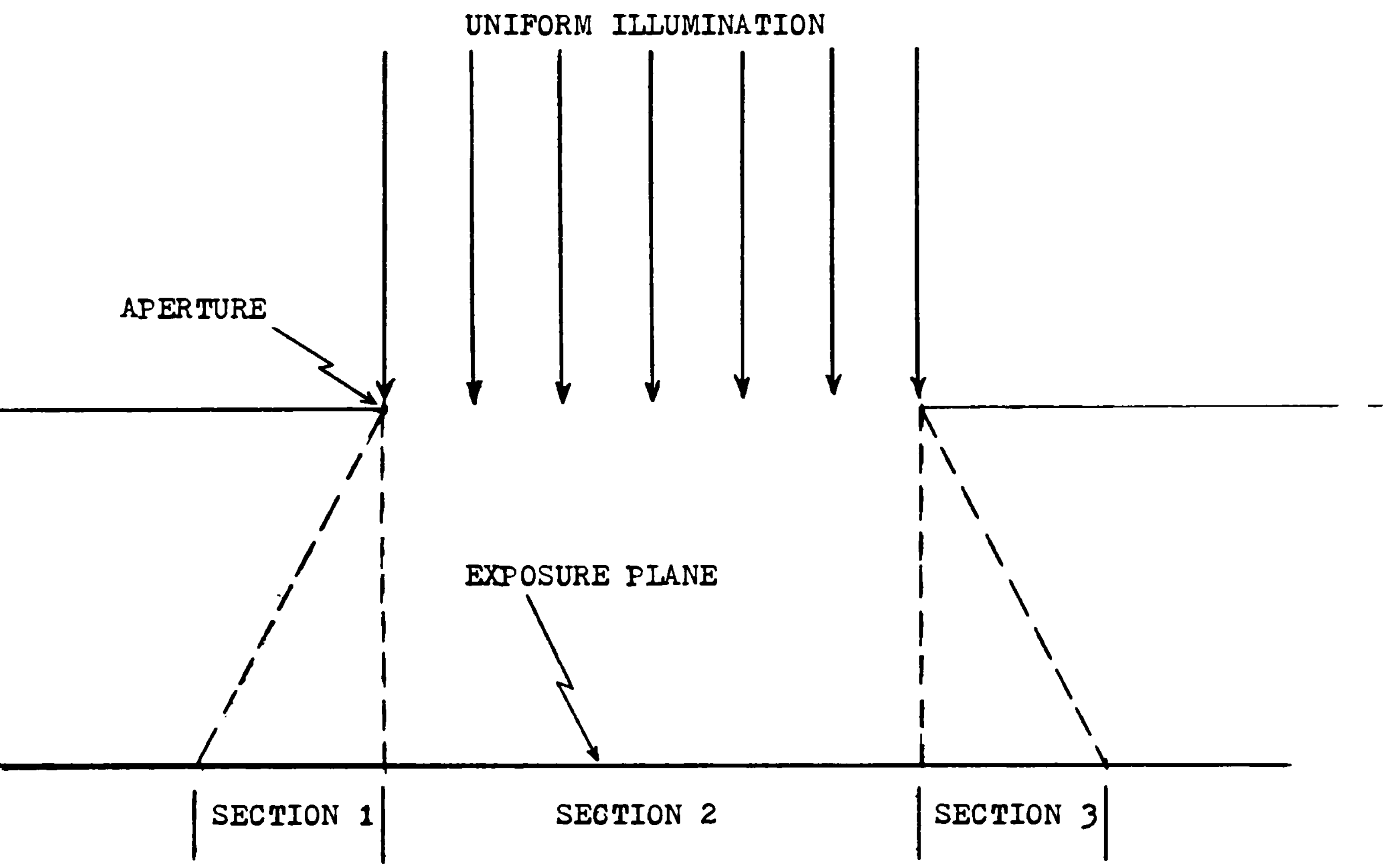

Figure 2: Illumination of exposure plane

motor step size) is needed. In order to solve this conflict of aperture width to step size ratio, the purpose of the filter would have to be evaluated and a compromise made somewhere between these two extremes

There is also another problem to consider. The stepper motor moves the film one step at a time when a signal from the controlling device is received. Because this is not a continuous motion, the film will be unevenly exposed unless the beginning of the steps fall exactly under the edge of the aperture,(Figure 3). In order to minimize this phenomenon, a large aperture width and a motor with a small angular step should be choosen.

The objectives of this study were to design and build a device that could make custom varying neutral density filters, and to empirically find an aperture width and step size to maximize the quality of the filters.

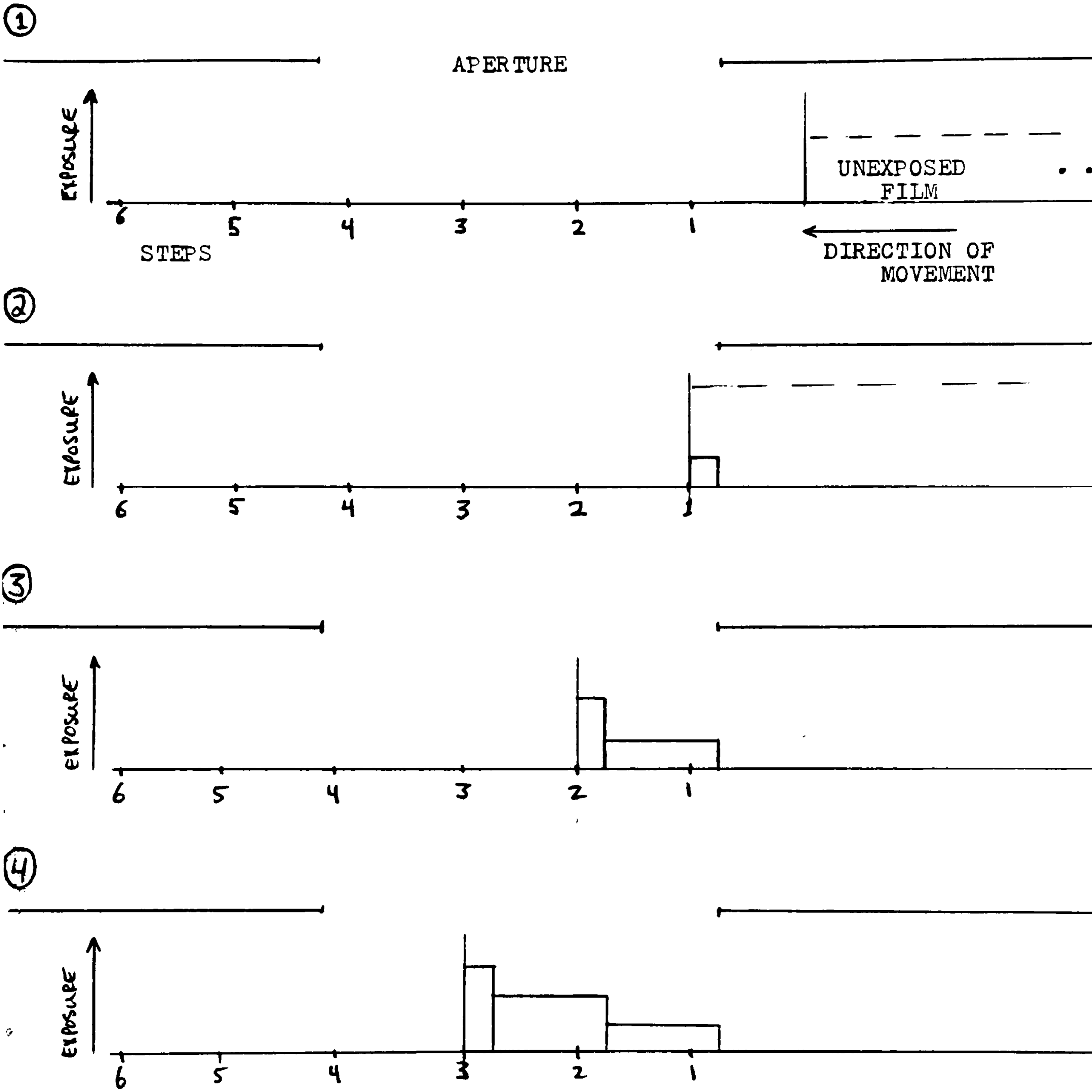

Figure 3: Example of how a non-uniform exposure could occur

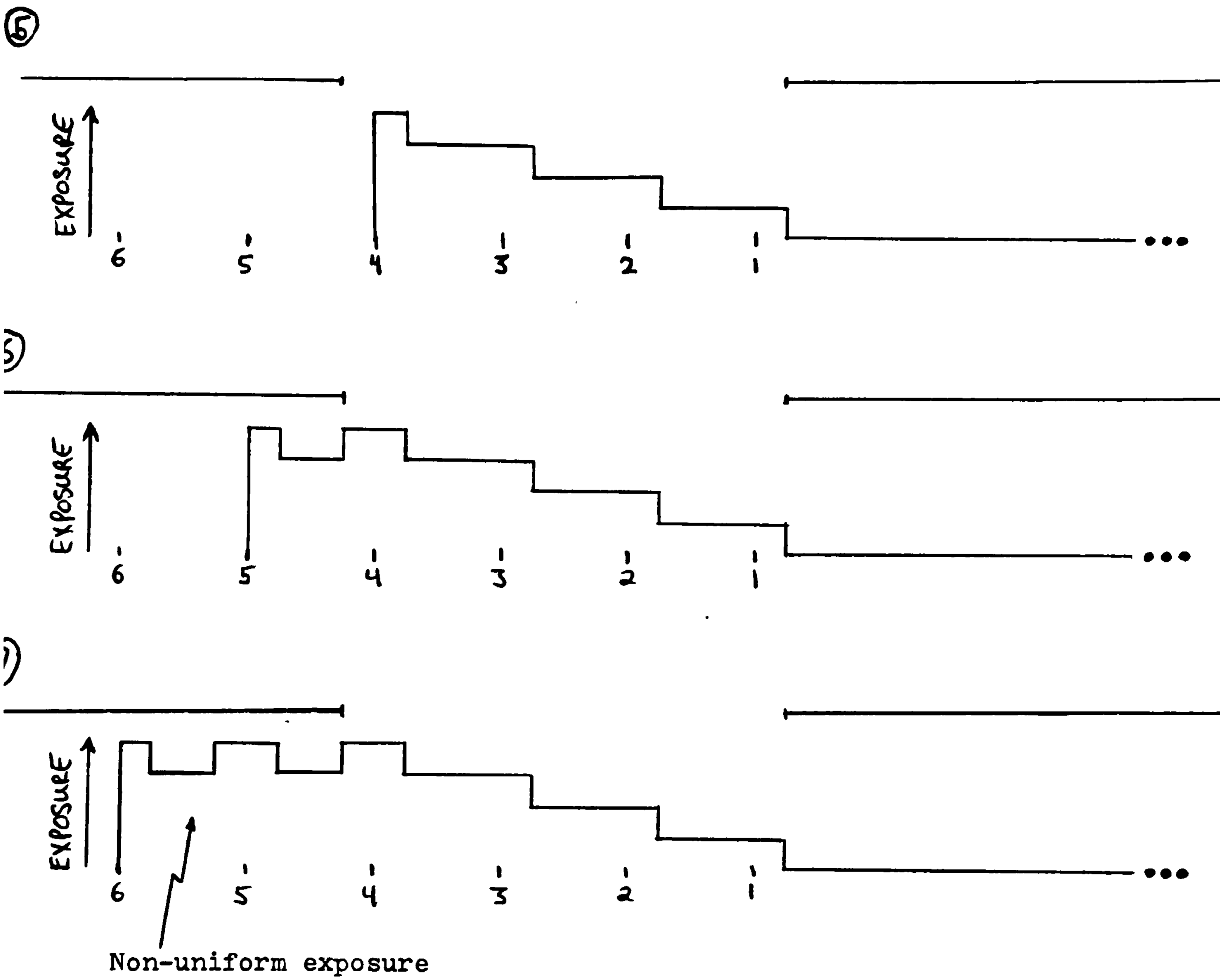

Figure 3 continued: As can be seen in (7) above, a non-uniform exposure has been made.

EXPERIMENTAL

A device was built incorporating the ideas of the conceptual diagram shown in Figure 1. The filters were made from Eastman Kodak Fine Grain Positive Film 7302, a low-speed, blue-sensitive, extremely fine grain film. Because of it's blue sensitivity it could safely be used under a Kodak 1A Safelight filter.

A vacuum frame held the film flat as it was moved past a slit aperture illuminated by a point light source. The vacuum frame was attached to a sliding rail. A Commodore-64 computer controlled the movement of the film via a stepper motor and interface board.

The film was developed in the MJP shown in Figure 4. A device was made that would hold a 3.5" x 6.5" jar in a power drill chuck. The drill, controlled by a Powerstat variable autotransformer, agitates the film and chemicals during development by spinning the jar at a desired RPM. The rest of the film processing was done by standard tray-rocking techniques.

There were several tests that were done to ensure the film processing technique was under control. The repeatability of the developing technique was evaluated by developing step wedges from a Kodak 101 Sensitometer. The best developing time also had to be found. These step tablets, made on Kodak Film Type 7302, were developed at various times and the results were evaluated in terms of low

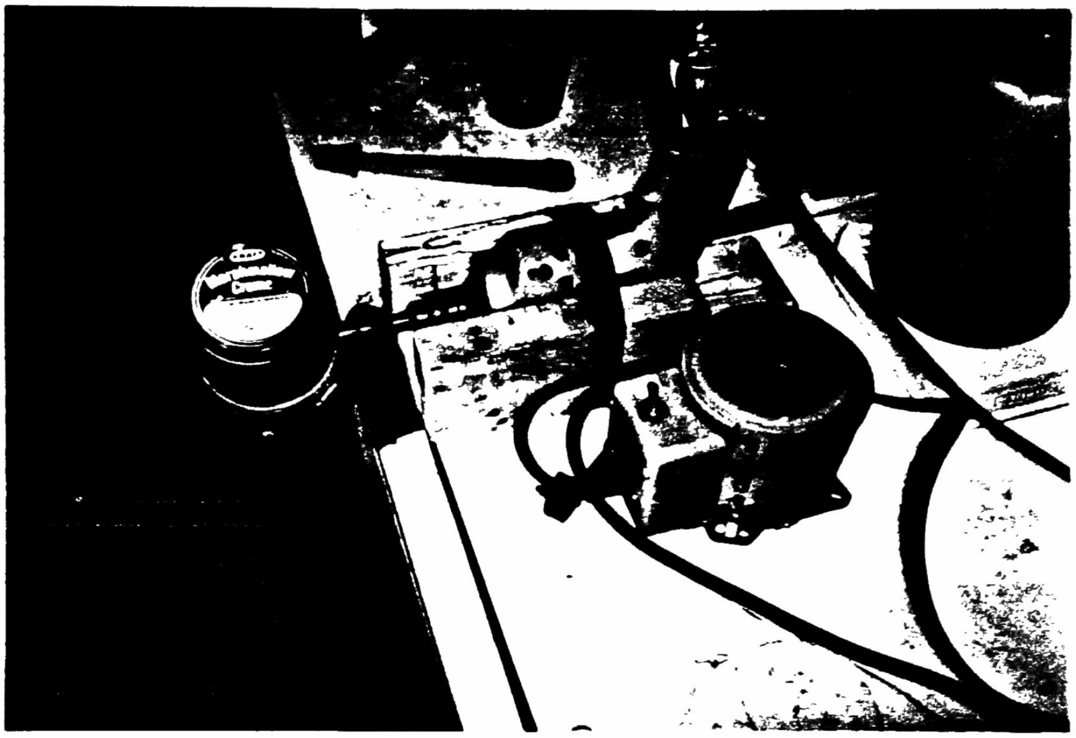

Figure 4 : Film Processor

base + fog level and repeatability of results. The speed of the MJF was determined by visual evaluation of the randomness of the agitation of the developer.

Several tests were conducted on the device and the light source. The uniformity of the illumination on the slit aperture was tested at three representative levels by separately exposing stationary sheets of film through the aperture and measuring the resultant density. To determine the effect of stray light, a uniform initial exposure was made on the film. This exposed film was put on the vacuum frame and a section of the film was completely covered. The aperture slot was also covered so only stray light would be able to reach the film. The device ran for several minutes with the light on and the film was developed and evaluated.

As a final check on the process uniformity, sheets of film were exposed uniformly, developed in the MJF, and the uniformity of the density checked.

A computer program was written to accept desired density or tranmittances as a function of distance. The program then controls the amount of exposure on every part of the film by delaying the time between steps.

By using a wedge shaped aperture and various step sizes, an appropriate aperture width and step length was empirically found.

The delay times between steps were then calibrated so the desired density profiles would be realized.

Microdensitometer scans were made of several samples to determine their uniformity and the maximum density gradient for a low density filter (.04-.34 density units).

RESULTS

As a result of this study, a workable device was built that can precisely expose film to make the desired variable neutral density filter,(Figures 5,6). A regulated voltage source provides power to the interface board (Figure 7, schematic shown in Figure 8) which connects the stepper motor and a Commodore-64 computer. The clock line (pin #18) on the L297 IC of the interface was connected to line PB6 of the User Port on the C-64. When the L297 IC detects a high-to-low voltage change on this line, it will move the stepper motor one step. Changing the voltage on this line is accomplished on the C-64 by changing the status of line PB6 from an output line to in input line. This is done by using two Poke statements in the controlling program,(see Appendix A).

One step with this stepper motor is a 1.8 degree rotation of the rotor. The belt drive attached to the motor and the vacuum frame carrier translates this step into a .15mm movement of the vacuum frame carrier. A double sided vacuum frame which can accomodate sheet film from 2" x 5" to 5.5" x 7.5" rests on top of the vacuum frame carrier and holds the film flat during exposure.

The film is shielded from the light by two covers, one that is stationary and one that can be swung up while loading the film. The ends of the covers are enclosed to prevent stray light from fogging the film. An aperture slot was cut

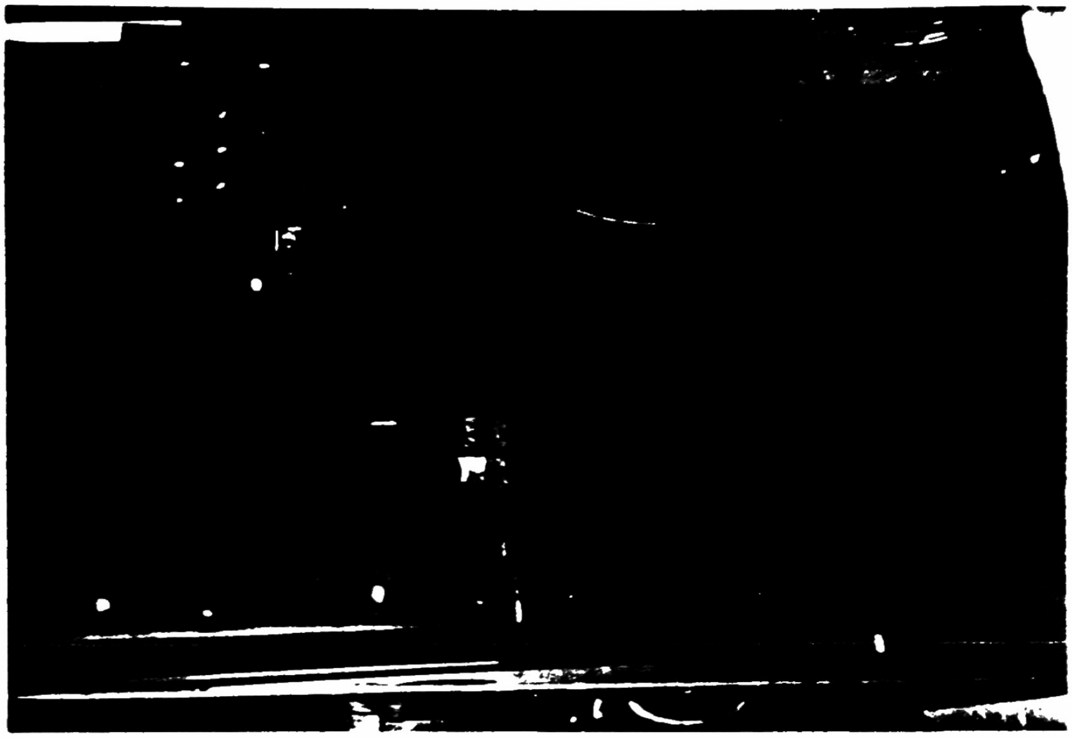

Figure 5 : Exposure modulator, shown here with covers in place.

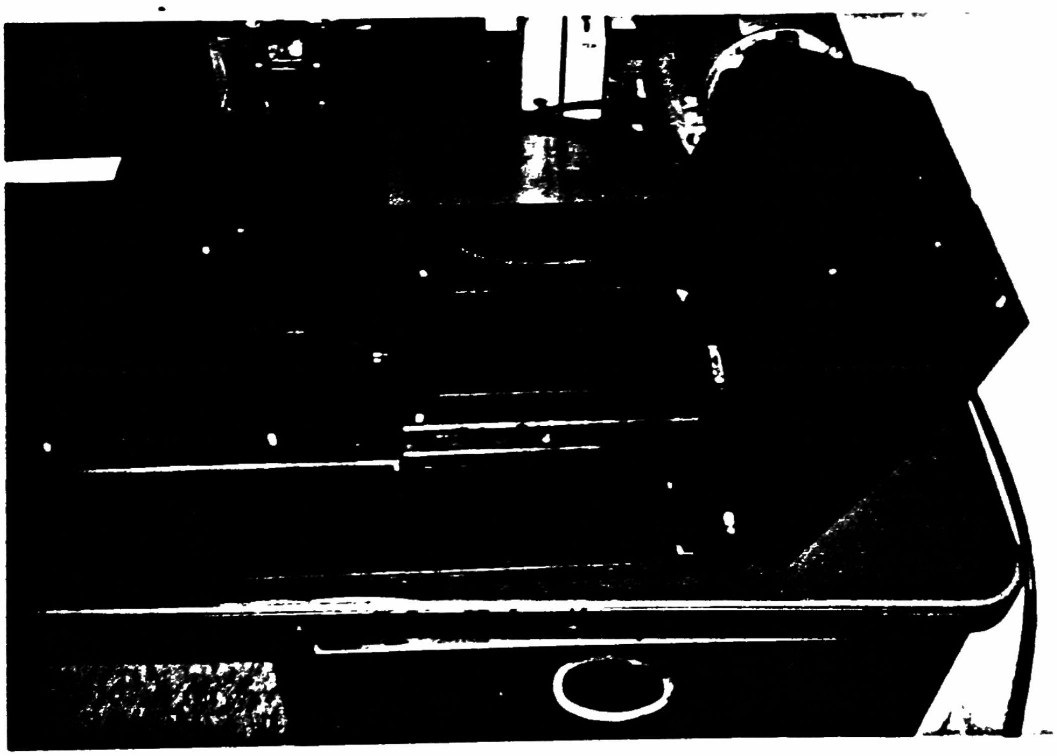

Figure 6 : Exposure modulator, shown here with one cover swung open to allow the loading or removal of film.

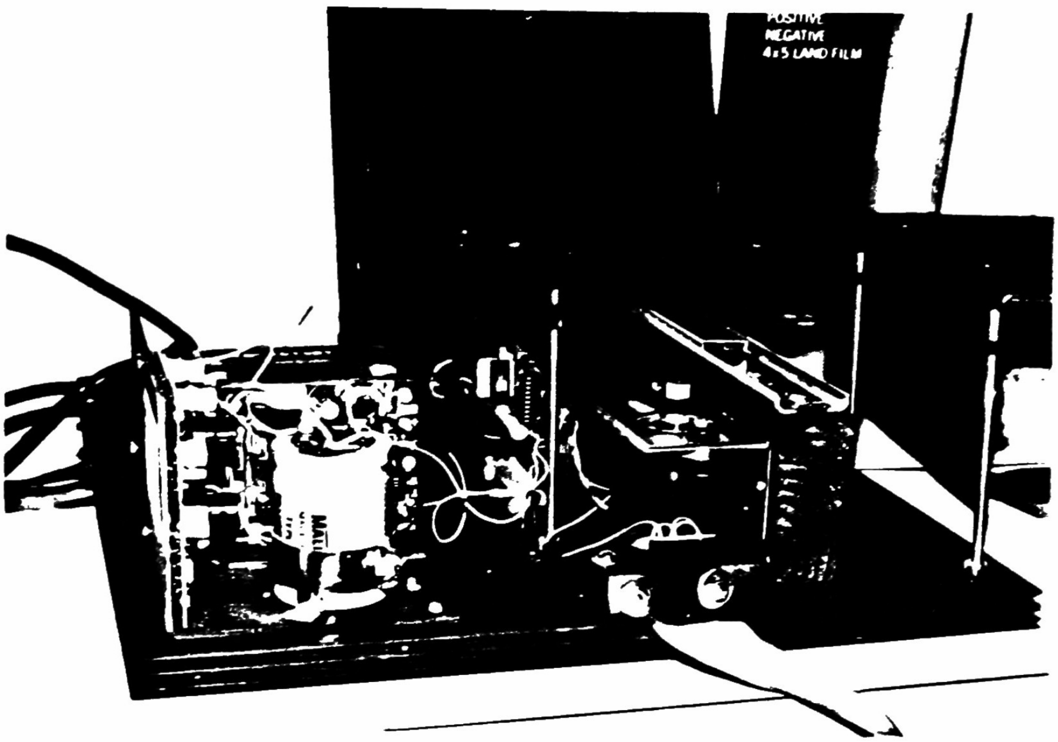

Figure 7 : Interface board, connecting the stepper motor, the power supply, and the controlling computer.

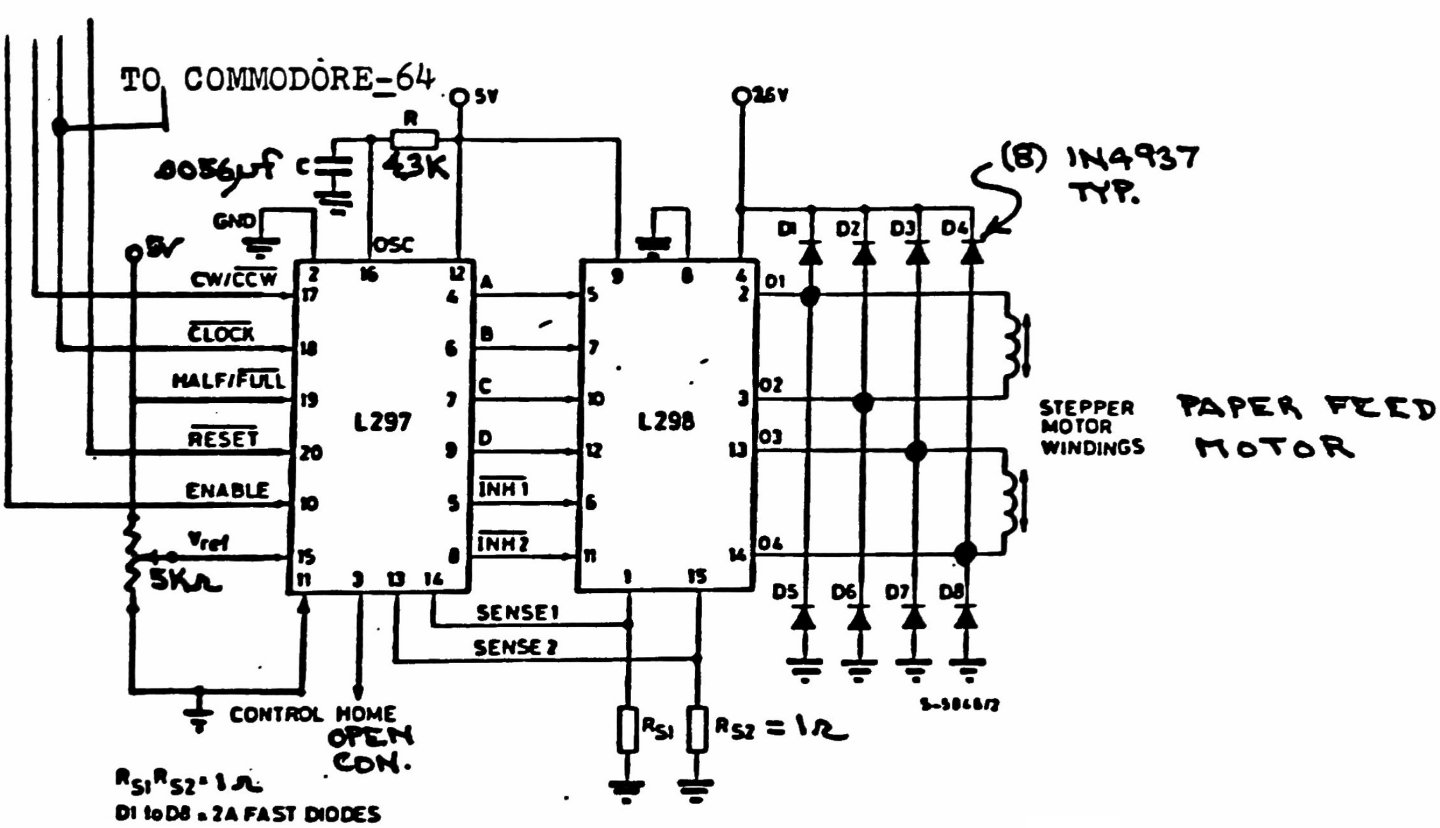

Figure 8 : Schematic of the interface.

in the stationary cover. The actual aperture is defined by masking off this slot with Scotch Tape No.850, a metallic sharp-edged tape.

An aperture width of 6.0mm was choosen to calibrate the computer programs, although any width from 3.0 to 7.0 mm would have worked also. This is because the step size of the motor is so small that the nonuniform exposure created by the stepping action cannot be seen visually.

All the covers and mounting boards were painted flat black to reduce the reflected light level.

A bullet safelight was used to house a General Electric T-8 light bulb. The safelight was modified by covering the open end with an opaque face that had a 2" diameter round opening in the center,(Figure 9). A filter holder was built under the opening so the light level could be adjusted easily by using the proper neutral density filters. A regulated current supply was built,(See Figure 10 , see Figure 11 for the circuit diagram) to power the light source. The supply has three main current levels. When calibrating the computer programs, the medium current level was used with a 2.00 N.D. filter in the light filter holder.

To determine the best development time the step tablets were developed for 4,5,6 and 7 minutes and the results are plotted in Figure 12. From these results, a four minute development time was choosen. The development schedule is shown in Table 1.

Figure 9 : Modification of the bullet safelight.

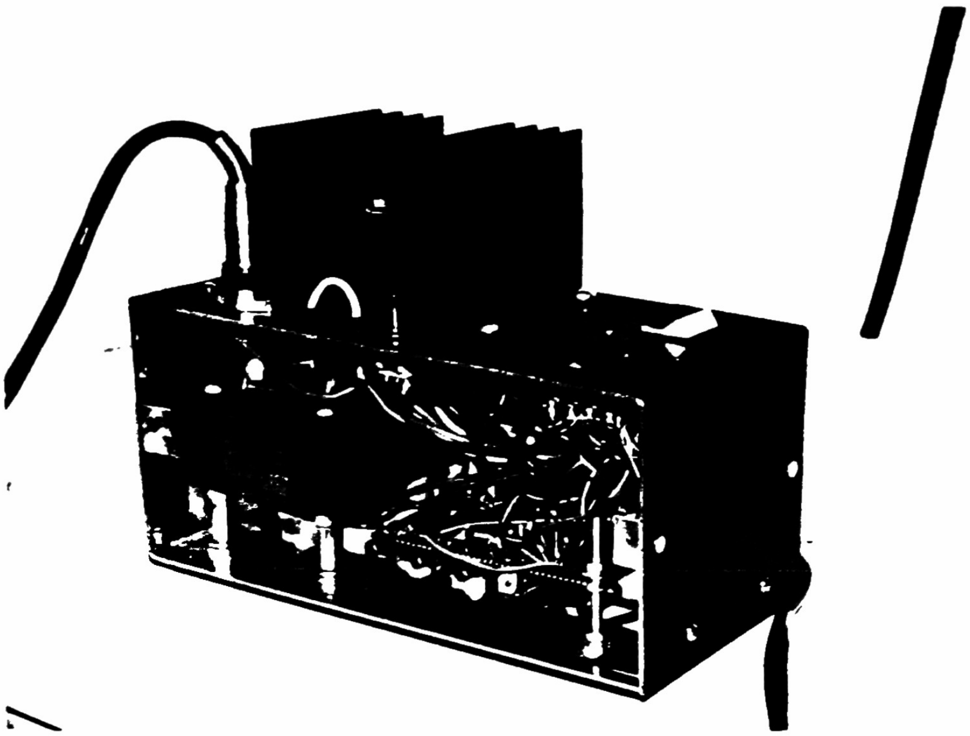

Figure 10: Regulated current source.

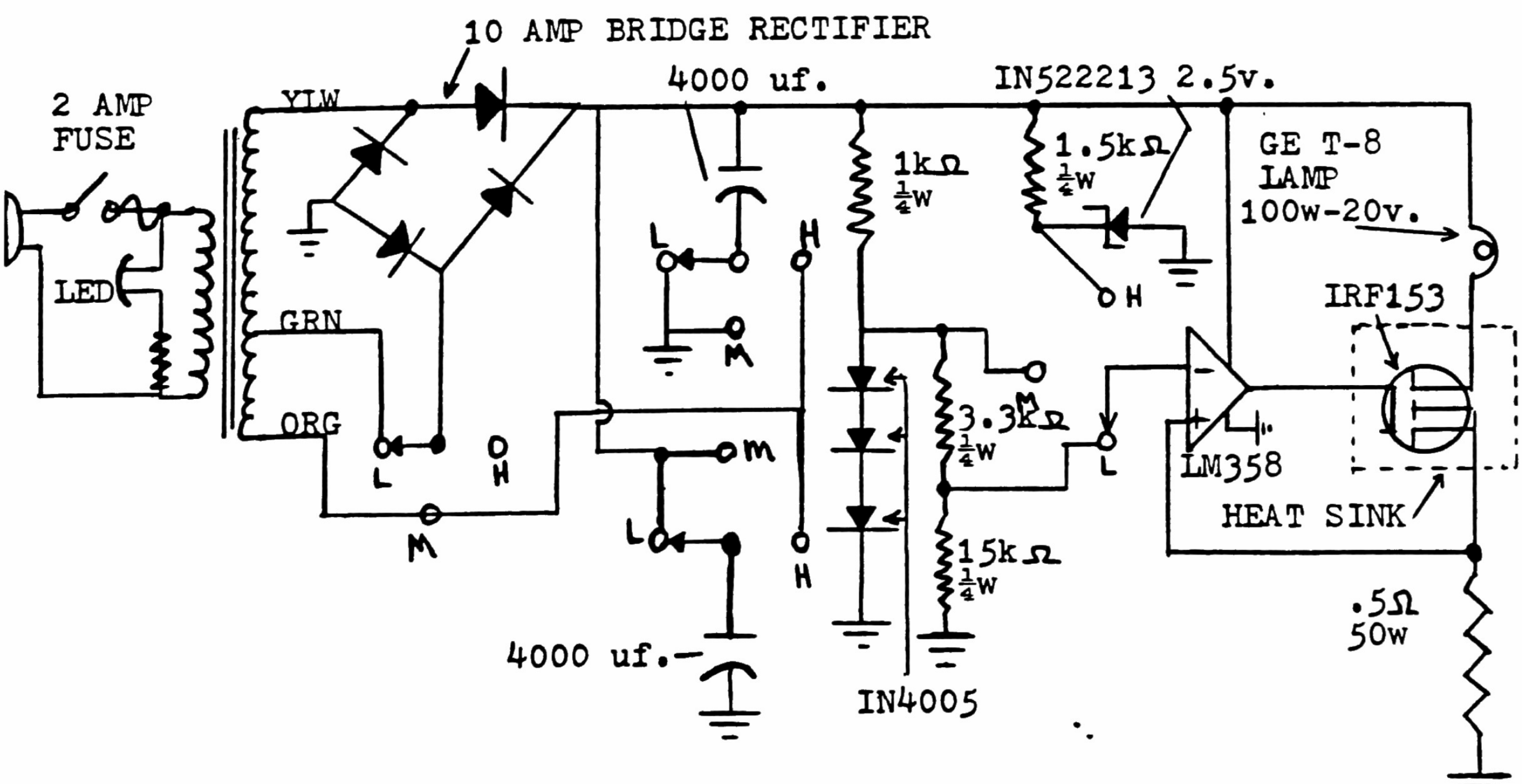

Figure 11: Circuit diagram of regulated current source.

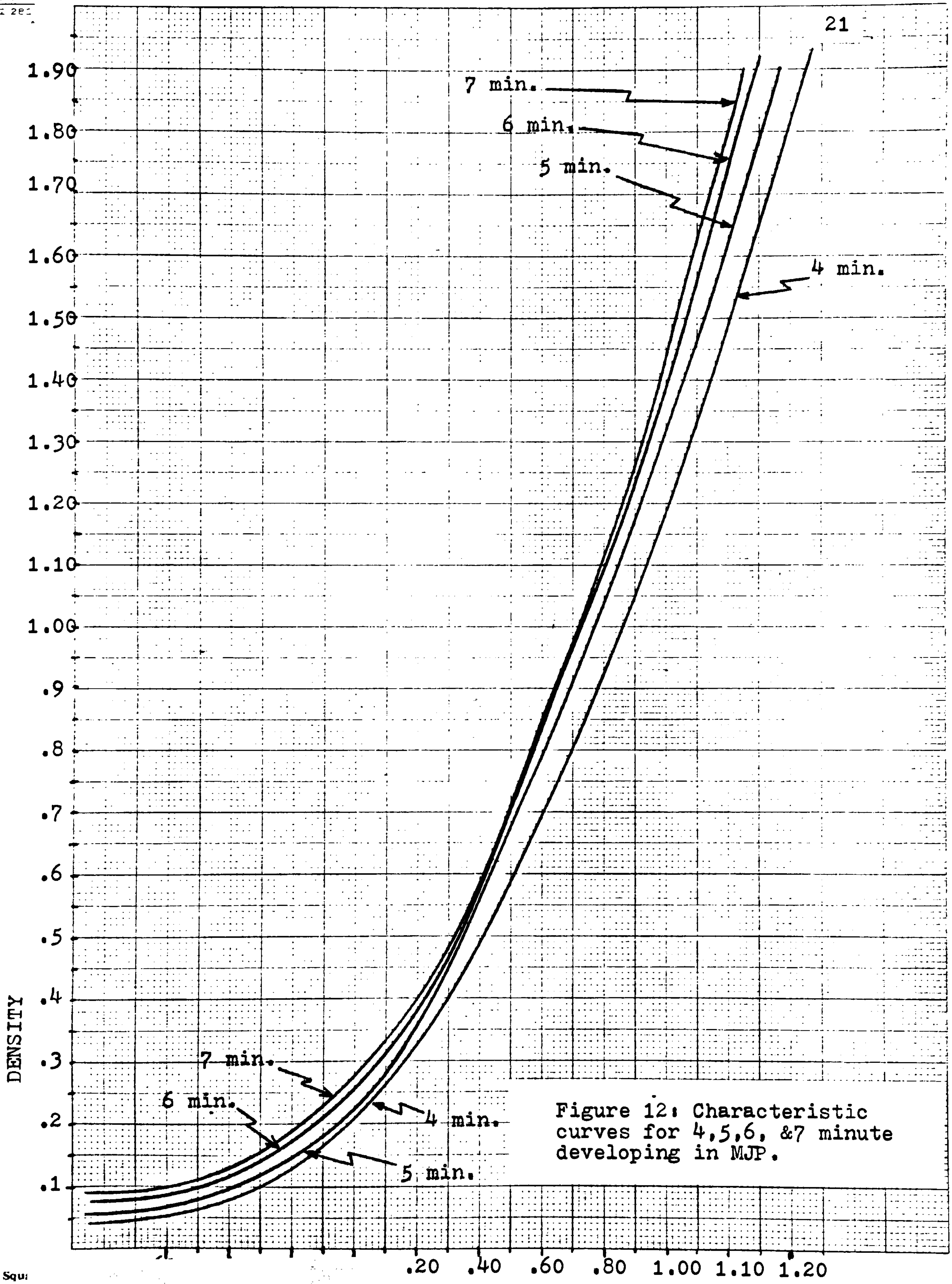

Figure 12: Characteristic curves for 4,5,6, &7 minute developing in MJP.

Development- Eastman Kodak D-76 @ 20 C for 4 min. in MJP

Kodak Stop Bath - 30 seconds

Kodak Fixer - 2 minutes

Kodak Hypo Clearing Agent - 3 minutes

Running water rinse - at 20 C for 8 minutes.

Kodak Photo - Flo - 30 seconds

Table 1.: Development schedule

The repeatability of the MJP determined by developing sensi strips was less than or equal to +/- .01 density units within a 99.5% confidence interval for densities less than .30 density units. Although the repeatability of the densities decreased with higher densities, the significance of the error remained the same as for the densities below the .30 density unit level. The best agitation of the developer was visually determined to occur when the speed of the MJP was 120 RPM. This corresponds to a setting on the VAT of 89 volts. It was also found that 240 cc. of developer at 120 RPM developed the film with almost perfect uniformity.

The densities on the film exposed at three representative levels of illumination were found to be constant for the entire length of the aperture slot.

The fog test yielded a sheet of uniform density with no indication of a section being covered. The uniformly exposed sheet film was processed according to the development schedule in Table 1. The resulting density was extremely uniform, having an average deviation of less than +/- .01 density units.

Microdensitometer scans are shown in Figures 13,14,15,16,& 17 of filters made with the program shown in Appendix B. These plots were made by scanning the filters in the same direction as the film was moved during exposure for a distance of 20 mm. The program where twelve sections of various densities are made on one filter.

These microdensitometer scans also show the maximum density gradient that can be made with the device calibrated as it is.

This device was calibrated to make low density (below .30 density units) filters, and these calibrations were incorporated into a program. This program is shown in Appendix A.

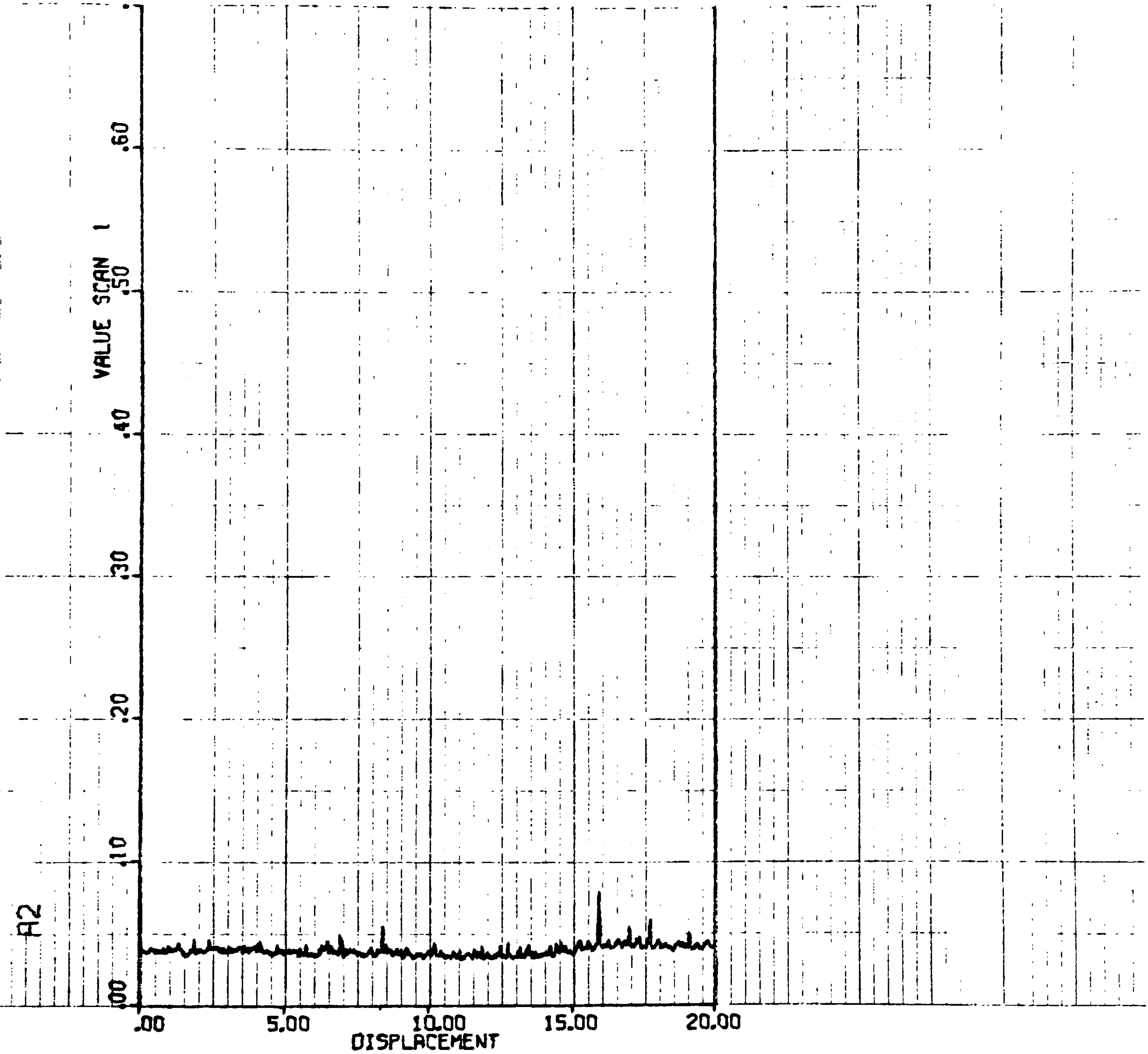

Figure 13 : Microdensitometer scan using a 10 um. aperture. The density from 0 to 10 (displacement) represents the base density. The displacement is in millimeters.

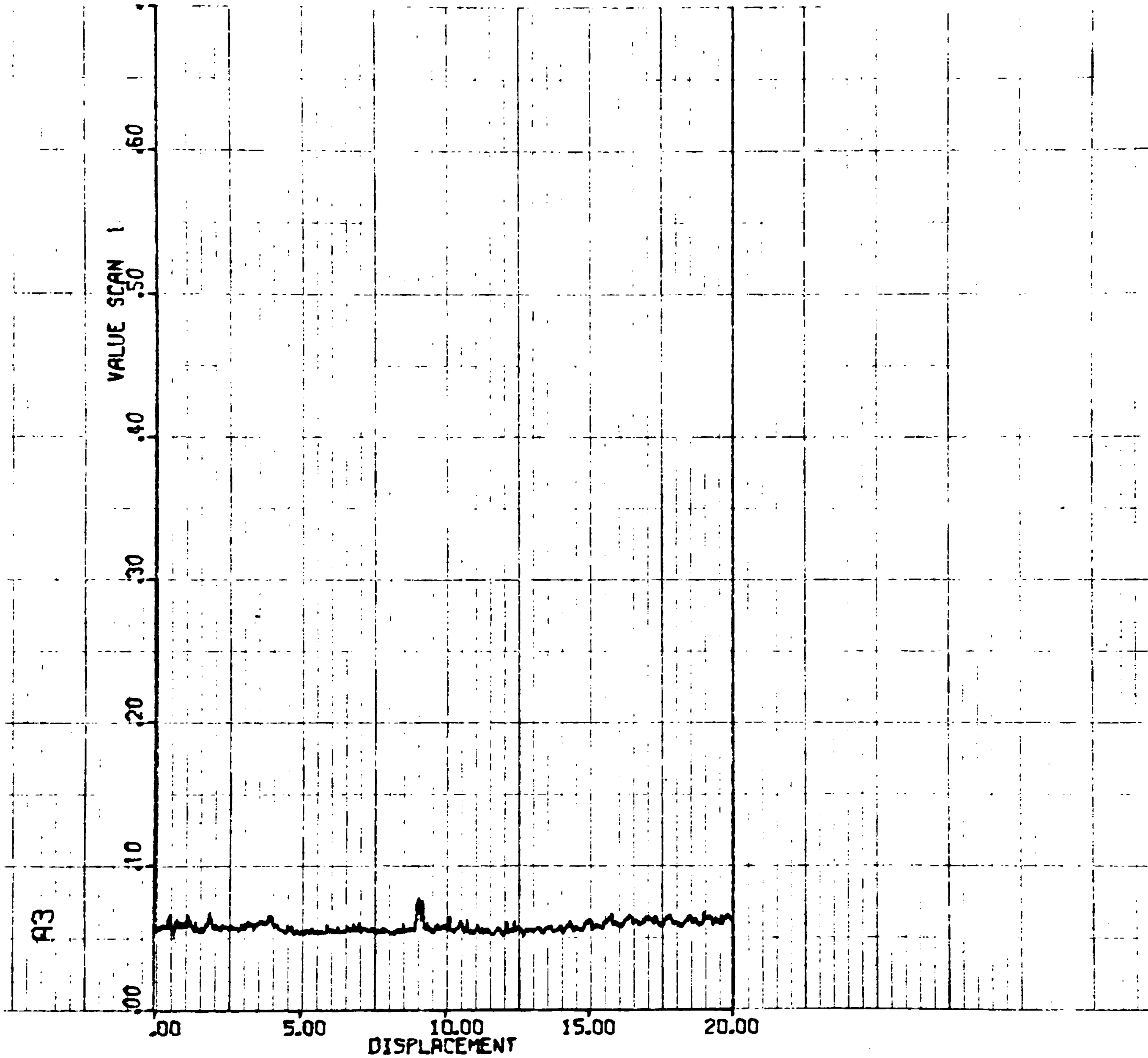

Figure 14 : Microdensitometer scan using a 10 um. aperture. The displacement is in millimeters.

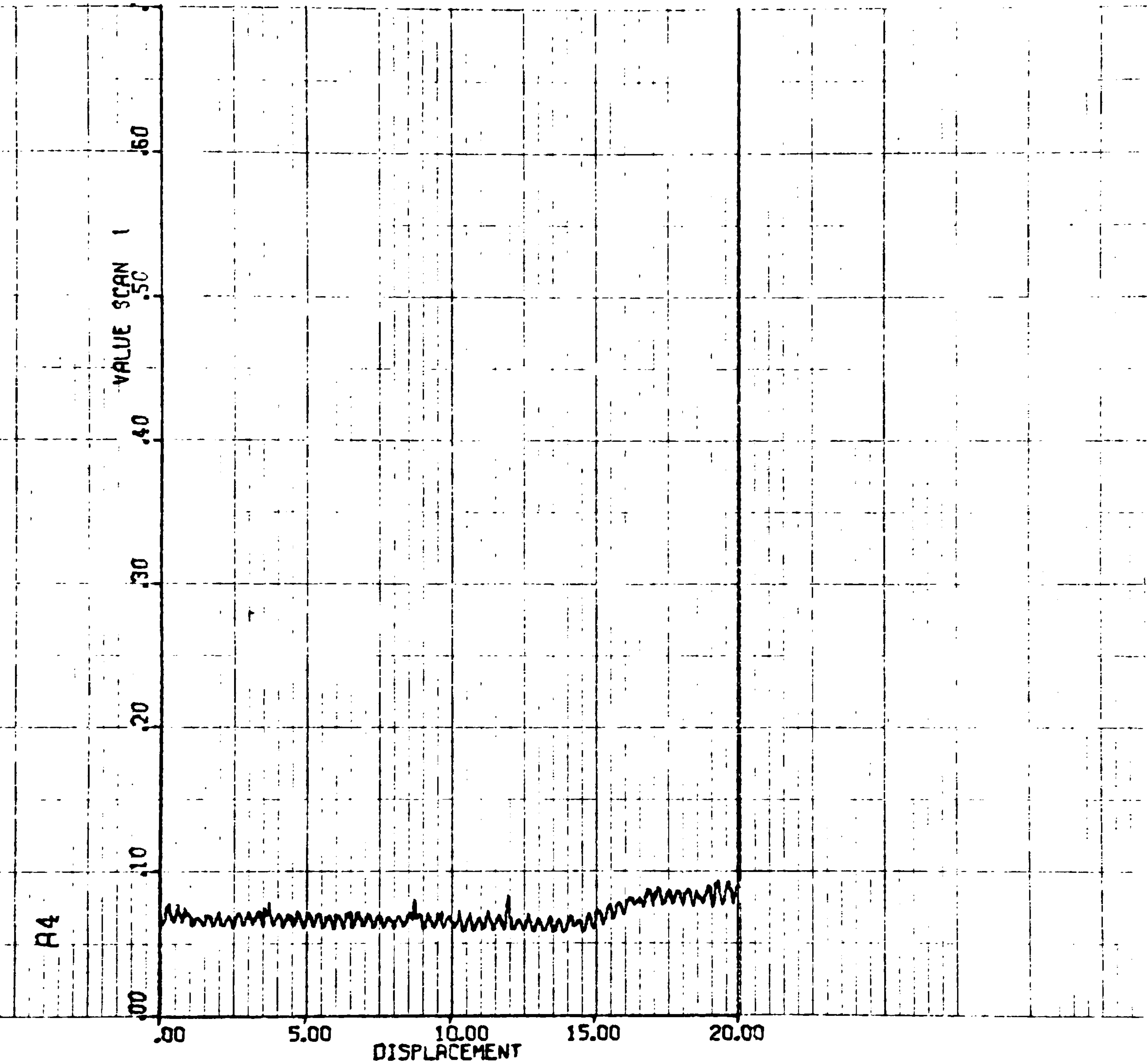

Figure 15 : Microdensitometer scan using a 10 um. aperture. The displacement is in millimeters.

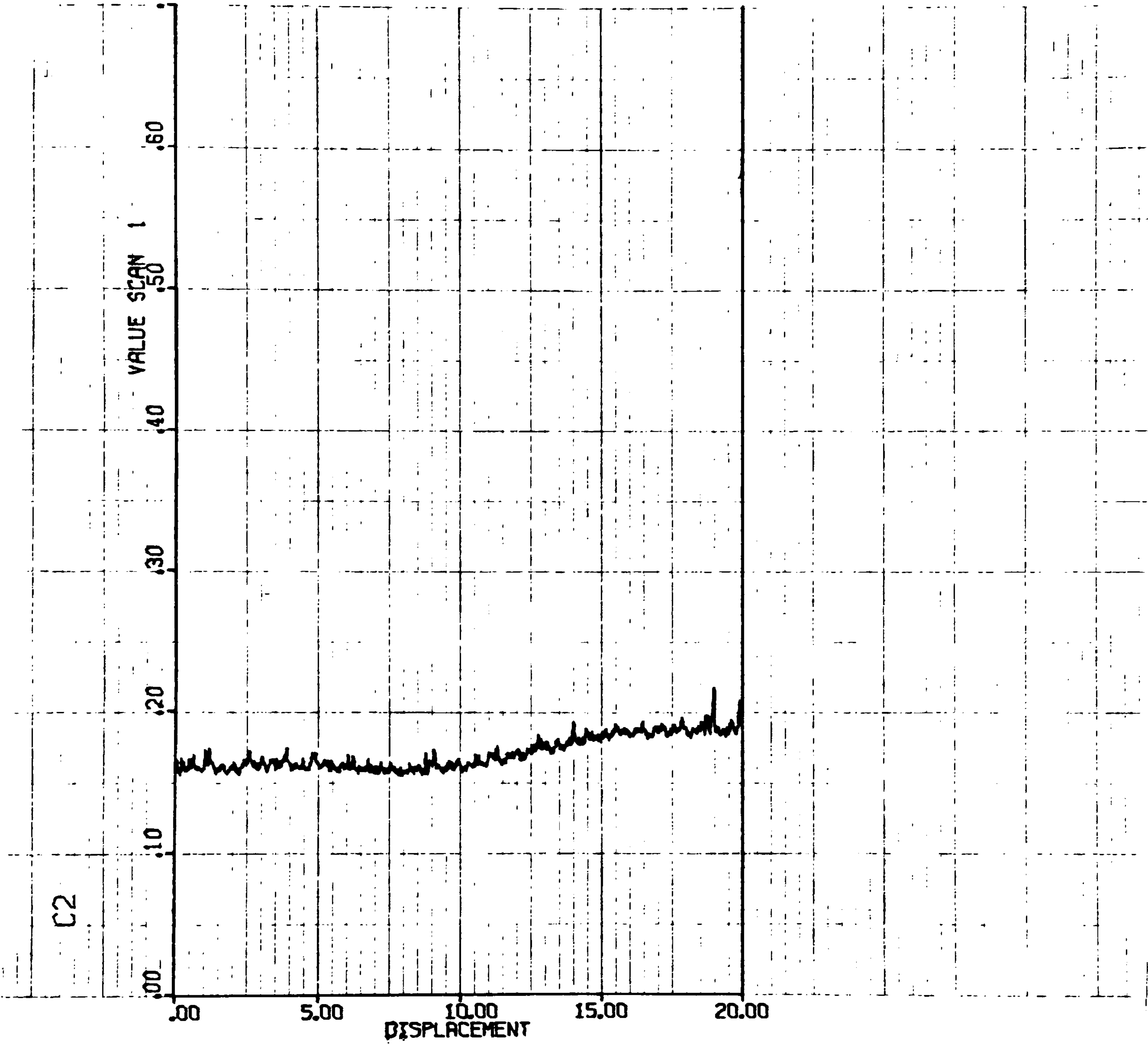

Figure 16 : Microdensitometer scan using an aperture of 10 um. The displacement is in millimeters.

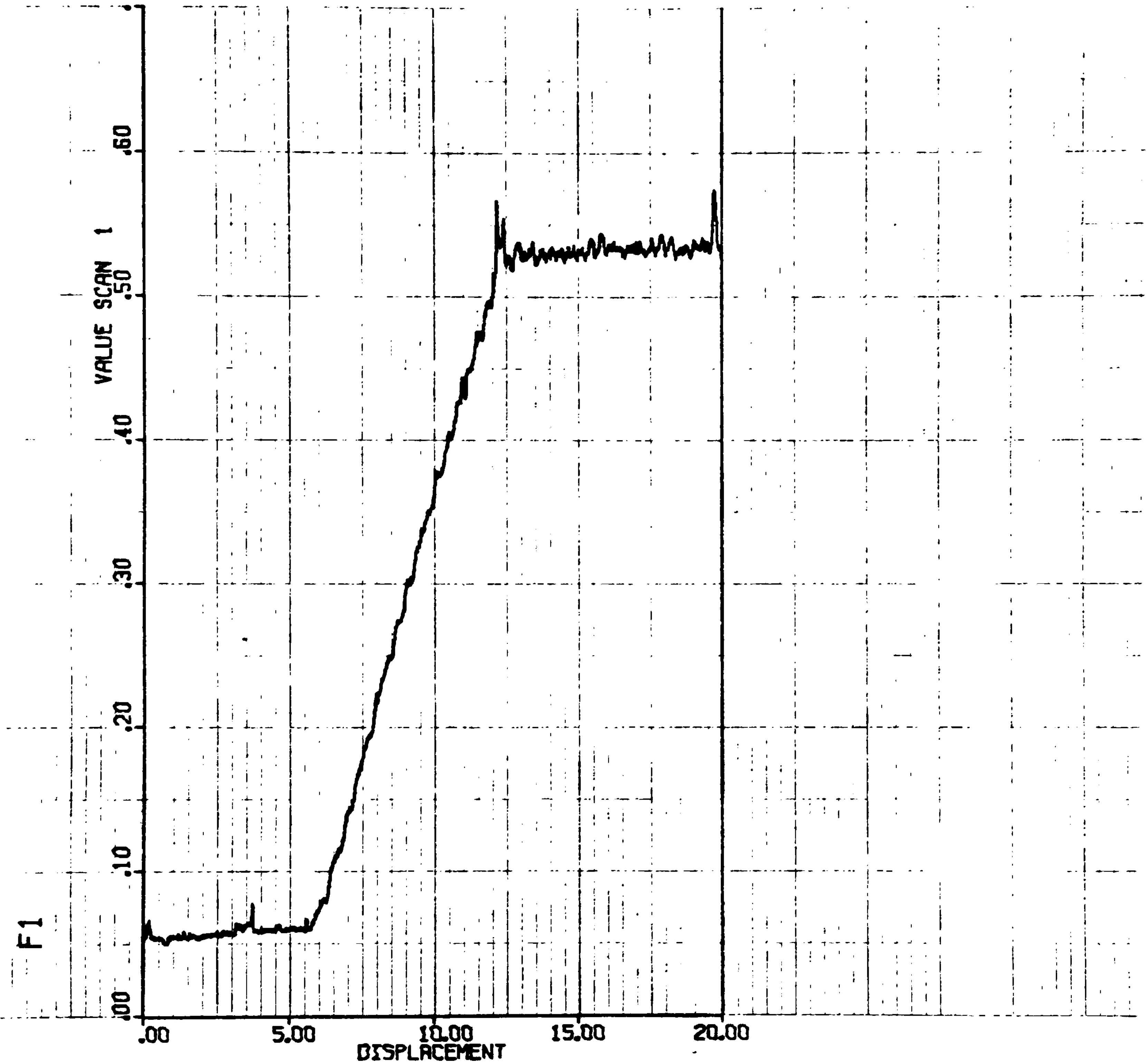

Figure 17 : Microdensitometer scan using an aperture of 10 um. The displacement is in millimeters.

DISCUSSION

The results of the uniformity of developing test and the repeatability of developing test show that the film processing technique is under control and will contribute an error less than or equal to +/- .01 density units. The illumination tests show that the slit aperture is evenly illuminated thereby yielding a constant exposure to the film for a given time interval.

The microdensitometer scans give some insight on the characteristics of the density profiles of the filters. Figure 13, from 0.00 to 13.00 mm, is a scan of the base density of the film. The level of noise associated with the base of the film could be thought of as the total dark noise of the microdensitometer and the film. This base noise should be kept in mind when evaluating the noise in the other scans.

The density scans are of several density profiles made for evaluating the filter generating process. One thing tried was to change the density by approximately .01 units. In Figure 14, a slightly longer exposure increased the density by .oo5 density units. In Figure 15, the density increased by .01. These results indicate a very sensitive exposure process.

Figure 16 shows another density profile that is increasing slightly. There is a little more noise present here, but this is expected at higher densities. On this filter a constant density was made for 10mm (o.oo to 10.oo mm on the scan) and then the density was slightly increased for the next 10 mm. The effect of this change and the distance it takes to make this change are clearly evident on this scan.

To examine the distance necessary to make a large change in density, a filter was made with a density change from .o5 to .53, shown in Figure 17. The distance the film moved during this transition, 5.40 mm., correlates well to the 5.8 mm. aperture used during this exposure. This helps verify the intuitive relationship between the aperture width and the minimum distance the film moves during a density change. Nonuniform densities caused by the step movement of the film were clearly visible when a motor with a step size of .84 mm was used. By using wedge shaped apertures, it was possible to find a "best" aperture to minimize this phenomenon. By going to a stepper motor with a smaller step length, it was possible to make these differences invisible to all but a microdensitometer.

The computer program has a great deal of flexibility for accomadating density profiles. There are a great number of different filters that can be made simply by entering the density values desired.

CONCLUSIONS

Custom variable neutral density filters can be made quickly and precisely using the device built during this study. A wide variety of filters could be made with only a low density calibration of the computer program. The acceptability of these filters depends on their application.

When examined visually or with a standard densitometer, these filters appear uniform. Microdensitometer scans revealed a small amount of noise in the densities. However, for many illumination systems requiring a low level of light attenuation to produce extreme uniformity, these filters could be placed in the light path where even much larger noise levels in the measured density would have no detrimental effects.

There is the capability in the filter generation program to pick a filter density profile from a "library" of density profiles stored on a disk. For future work, density profiles could be made and stored in this library. Also, this device needs to be calibrated in order to produce filters with a density over .34. Since the software framework for both has already been done, this would be easy to do.

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11. IBID, p.768.

12. IBID, p.190.

```
5 DIM A(25). B(25)
10 FRINT"morning sack. i've been waiting for you."
30 print"let's get started."
35 for x = 1 to 500
36 next x
110 print"what do ya wanna do today?"
130 print"your choices are:"
140 print"design a filter...................d"
150 print"choose a filter from memory........c"
160 print"read jokes and drink beer..........r"
165 print"select letter <return>"
170 input x$
180 if  x$= "d" then 1500
190 if  x$= "c" then 4000
200 if  x$= "r" then 6000
210 goto 170
1500 rem
1795 print"   you will enter 24 desired densities or transmittances which"
1960 print"WILL CORRESFOND TO THE FOLLOWING DIAGRAM:"
1961 FRINT"<space bar>"
1962 get x$:if x$ = "" then 1962
1965 print"  \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\x"
2011 for i = 1 to 3
2012 print"  ↓  ↓  ↓  ↓  ↓  ↓  ↓/ ↓  ↓/ ↓  ↓  ↓  ↓"
2013 next i
2014 print"- ↓m ↓n ↓o ↓p ↑q ↓r ↓s ↓t ↓u ↓v ↓w ↑x ↓"
2016 for i = 1 to 3
2017 print"  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓"
2018 next i
2019 print"  ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ"
2022 print"(lower diagram is a continuation of top)"
2025 print"<space bar>"
2030 get a$: if a$= "" then 2030
2035 print"are you entering:"
2040 print"density.............<d>"
2042 print"-or-"
2045 print"transmittnce........<t>"
2050 print"select <t> or <d>, & <return>."
2060 input x$:if x$ = "" then 2060
2070 print"enter data:"
2100 input "enter data pt. 1";a(1)
2105 input "enter data pt. 2";a(2)
2110 input "enter data pt. 3";a(3)
2115 input "enter data pt. 4";a(4)
2120 input "enter data pt. 5";a(5)
2125 input "enter data pt. 6";a(6)
2130 input "enter data pt. 7";a(7)
2135 input "enter data pt. 8";a(8)
2140 input "enter data pt. 9";a(9)
2145 input "enter data pt. 10";a(10)
2150 input "enter data pt. 11";a(11)
2155 input "enter data pt. 12";a(12)
2158 input "enter data pt. 13";a(13)
2160 input "enter data pt. 14";a(14)
2163 input "enter data pt. 15";a(15)
2166 input "enter data pt. 16";a(16)
2169 input "enter data pt. 17";a(17)
2173 input "enter data pt. 18";a(18)
2176 input "enter data pt. 19";a(19)
2179 input "enter data pt. 20";a(20)
2182 input "enter data pt. 21";a(21)
2185 input "enter data pt. 22";a(22)
```

```
2188 input "enter data pt. 23";a(23)
2192 input "enter data pt. 24";a(24)
2193 if x$ = "d" then 2200
2194 for i = 1 to 24
2196 z = 100  * (log(1/a(i))/log(10)):y=int(z):a(i) = y/100
2198 next i
2200 for i = 1 to 24
2205 if a(i) < = .05 then b(i) = 1
2210 if a(i)   = .06 then b(i) = 15
2215 if a(i)   = .07 then b(i) = 50
2220 if a(i)   = .08 then b(i) = 100
2225 if a(i)   = .09 then b(i) = 110
2230 if a(i)   = .10 then b(i) = 125
2235 if a(i)   = .11 then b(i) = 133
2240 if a(i)   = .12 then b(i) = 150
2245 if a(i)   = .13 then b(i) = 160
2250 if a(i)   = .14 then b(i) = 173
2255 if a(i)   = .15 then b(i) = 185
2260 if a(i)   = .16 then b(i) = 200
2265 if a(i)   = .17 then b(i) = 210
2270 if a(i)   = .18 then b(i) = 225
2275 if a(i)   = .19 then b(i) = 237
2280 if a(i)   = .20 then b(i) = 250
2285 if a(i)   = .21 then b(i) = 260
2290 if a(i)   = .22 then b(i) = 280
2295 if a(i)   = .23 then b(i) = 300
2300 if a(i)   = .24 then b(i) = 325
2305 if a(i)   = .25 then b(i) = 350
2306 if a(i)   = .25 then b(i) = 380
2310 if a(i)   = .27 then b(i) = 425
2315 if a(i)   = .28 then b(i) = 450
2320 if a(i)   = .29 then b(i) = 500
2325 if a(i)   = .30 then b(i) = 550
2330 if a(i)  >  .30 then b(i) = 700
2335 next i
2340 open 4,4
2342 for i = 1 to 24
2344 print#4, "density of section";i;"="a(i);"........delay=";b(i)
2346 next i
2348 close 4,4
2350 print"program is set up"
2355 print"set current control to medium and place 2.00 nd filter in lamp."
2358 print"**take disk out of the disk drive**"
2360 print"turn off television. press space bar    to start."
2365 get x$:if x$ = "" then 2365
2400 rem this smidgit moves the film to the edge of the aperture
2405 for i = 1 to 27
2410 poke 56579,64:poke 56579,0
2415 for l = 1 to b(1)
2420 next l
2425 next i
2500 for n = 1 to 24
2550 for i = 1 to  9
2555 poke 56579,64:poke 56579,0
2560 for l = 1 to b(n)
2565 next l
2570 next i
2575 next n
2580 goto 110
4000 print"there are no filters in memory at this time.<space bar>"
4002 get a$:if a$ = "" then 4002
4003 goto 110
6000 print"forget it, you lazy sack."
6002 print"make another choice. <space bar>"
6003 get a$:if a$ = "" then 6003
6004 goto 110
```

```
5 dim a(15). b(15)
10 print"morning sack. i've been waiting for you."
30 print"let's get started."
35 for x = 1 to 2000
36 next x
110 print"what do ya wanna do today?"
130 print"your choices are:"
140 print"design a filter....................d"
150 print"choose a filter from memory........c"
160 print"read jokes and drink beer..........r"
165 print"select letter <return>"
170 input x$
180 if  x$= "d" then 1500
190 if  x$= "c" then 4000
200 if  x$= "r" then 6000
210 goto 170
1500 rem
1505 print"   you will enter 12 desired densities or transmittances which"
1960 print"WILL CORRESPOND TO THE FOLLOWING DIAGRAM:"
2000 PRINT"  \\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\\x"
2002 FOR I = 1 TO 3
2004 PRINT"  ↓  ↓  ↓  ↓  ↓  ↓  ↓' ↓  ↓' ↓  ↓  ↓  ↓"
2005 NEXT I
2008 PRINT"  ↓A ↓B ↓C ↓D ↓E ↓F ↓G ↓H ↓I ↓J ↓K ↓L ↓"
2010 FOR I = 1 TO 3
2015 PRINT"  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ↓"
2020 NEXT I
2022 PRINT"  IIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIIII"
2025 PRINT"<space bar>"
2030 get a$: if a$= "" then 2030
2035 print"are you entering:"
2040 print"density.............<d>"
2042 print"-or-"
2045 print"transmittnce........<t>"
2050 print"select <t> or <d>, & <return>."
2060 input x$:if x$ = "" then 2060
2066 if x$ = "d" then 2100
2067 if x$ = "t" then 2070
2068 goto 2060
2070 print"enter data:"
2100 input "enter data pt. 1";a(1)
2105 input "enter data pt. 2";a(2)
2110 input "enter data pt. 3";a(3)
2115 input "enter data pt. 4";a(4)
2120 input "enter data pt. 5";a(5)
2125 input "enter data pt. 6";a(6)
2130 input "enter data pt. 7";a(7)
2135 input "enter data pt. 8";a(8)
2140 input "enter data pt. 9";a(9)
2145 input "enter data pt. 10";a(10)
2150 input "enter data pt. 11";a(11)
2155 input "enter data pt. 12";a(12)
2200 for i = 1 to 12
2203 if a(i) < = .04 then b(i) = 0
2205 if a(i)   = .05 then b(i) = 8
2210 if a(i)   = .06 then b(i) = 13
2215 if a(i)   = .07 then b(i) = 17
```

```
2220 if a(i)   = .08 then b(i) = 20
2225 if a(i)   = .09 then b(i) = 22
2230 if a(i)   = .10 then b(i) = 25
2235 if a(i)   = .11 then b(i) = 28
2240 if a(i)   = .12 then b(i) = 31
2245 if a(i)   = .13 then b(i) = 33
2250 if a(i)   = .14 then b(i) = 35
2255 if a(i)   = .15 then b(i) = 37
2260 if a(i)   = .16 then b(i) = 38
2265 if a(i)   = .17 then b(i) = 39
2270 if a(i)   = .18 then b(i) = 41
2275 if a(i)   = .19 then b(i) = 46
2280 if a(i)   = .20 then b(i) = 54
2285 if a(i)   = .21 then b(i) = 56
2290 if a(i)   = .22 then b(i) = 59
2295 if a(i)   = .23 then b(i) = 61
2300 if a(i)   = .24 then b(i) = 64
2305 if a(i)   = .25 then b(i) = 66
2306 if a(i)   = .26 then b(i) = 68
2310 if a(i)   = .27 then b(i) = 71
2315 if a(i)   = .28 then b(i) = 78
2320 if a(i)   = .29 then b(i) = 86
2325 if a(i)   = .30 then b(i) = 100
2330 if a(i)   >  .30 then b(i) = 150
2335 next i
2340 open 4,4
2342 for i = 1 to 12
2344 print#4, "data point";i;"=";a(i):print#4, "delay=";b(i)
2346 next i
2348 close 4,4
2350 print"program is set up"
2355 print"set current control to medium and place 2.00 nd filter in lamp."
2360 print"turn off television. press space bar    to start."
2365 get x$:if x$ = "" then 2365
2400 rem this smidgit moves the film to the edge of the aperture
2405 for i = 1 to 150
2410 poke 56579,64:poke 56579,0
2415 for l = 1 to b(1)
2420 next l
2425 next i
2500 for n = 1 to 12
2550 for i = 1 to 75
2555 poke 56579,64:poke 56579,0
2560 for l = 1 to b(n)
2565 next l
2570 next i
2575 next n
2580 goto 110
4000 print"there are no filters in memory at this time.<space bar>"
4002 get a$:if a$ = "" then 4002
4003 goto 110
6000 print"forget it, you lazy sack."
6002 print"make another choice. <space bar>"
6003 get a$:if a$ = "" then 6003
6004 goto 110

ready.
```

VITA

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